ARTIFICIAL REGENERATION OF MULTIPLE HARDWOOD SPECIES TO DEVELOP SPECIFIC FOREST COMMUNITIES[1]

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Abstract—A five-species mixed hardwood plantation consisting of *Liqudambar styraciflua*, *Quercus michauxii*, *Q. pagoda*, *Fraxinus pennsylvanica*, and *Carya aquatica* has been established at the National Environmental Research Park, New Ellenton, SC. All were grown under uniform conditions with the same nursery fertility protocol. Individual trees for outplanting were chosen from approximately the best 50 percent of the nursery crop for each species based upon a combination of first-order lateral root characteristics, heights, and root collar diameters. All trees were free-to-grow at the end of the fifth growing season. Fifth year survival runs between 83 and 100 percent. Sweetgum and green ash are the largest with heights of 3.77 and 3.71 m and diameters of 4.53 and 3.08 cm, respectively. Sweetgum stem volume exceeds the others by 2-14 times. All species are represented in the main crown canopy and the high vigor of most trees suggests this mixture can be maintained.

INTRODUCTION

The hardwood forests of the Southern U.S. are not naturally composed of single, predominant species. The diversity of tree species within these stands is one of the qualities that makes them so valuable for multiple use stand management. The characteristic species of the various hardwood forest types dictates the sustainability, stability, and level of appropriate human activity tolerated within each stand.

The emphasis on artificial regeneration in the Southeastern U.S. has been with single-species conifer plantations. Successful wide-scale hardwood plantings have been difficult to achieve. Three primary factors may be responsible for this low rate of success. First, overstory competition is quite deleterious to seedlings because it delays recovery from transplant shock. The degree to which overtopping shade prevents seedlings from thriving is frequently underestimated. Second, seemingly minor soil variations within the planting site may significantly impact hardwood root establishment. Last, until recently, obtaining competitive, high quality hardwood planting stock in the Southern U.S. has been difficult (Williams and Hanks 1994). Standards for growing and grading planting stock were not available. Furthermore, reliable nursery production is also severely impacted by periodicity in hardwood seed production. Mother trees of specific species with desired characteristics cannot be relied upon to produce adequate annual seed crops.

While many of the best hardwood sites have been planted to pines since the 1950's, some proportion of these pine stands now being harvested may need to be reforested to mixed hardwood stands to achieve desired biological diversity and to provide increased flexibility to forest managers. Recently, nursery protocols were reported that permit reliable hardwood seedling production and that define grading criteria for identifying a seedling's future competitive potential (Kormanik and others 1994 a,b).

The objective of this research is to evaluate stand development when five species, produced under a uniform nursery protocol and graded according to specific standards for each species, are outplanted on a common site. The overall goal is to artificially establish a biologically diverse, mixed hardwood stand.

METHODS

Mother trees for five species were selected from an area managed by the USDA Forest Service in the National Environmental Research Park (Savannah River Natural Resource Management and Research Institute, New Ellenton, SC). The species were cherrybark oak (CB, *Quercus pagoda* Raf.), swamp chestnut oak (SC, *Q. michauxii* Nutt.), green ash (GA, *Fraxinus pennsylvanica* Marsh.), sweetgum (SG, *Liquidambar styraciflua* L.), and water hickory (WH, *Carya aquatica* Nutt.). Seeds were collected in the fall of 1992. Depending upon species and availability of seed, anywhere from 12 to 20 mother trees were selected and netted prior to seed fall. The seeds for each species were composited prior to sowing and sent to the Georgia Forestry Commission's Flint River Nursery.

All species were grown according to the nursery soil fertility protocol reported earlier (Kormanik and others 1994b). The soil was first fumigated with methyl bromide, then amended to the fertility levels desired for hardwood seedling production. At this location, based upon a standard double acid soil extraction, the levels of Ca, K, P, Mg, Cu, Zn, and B were adjusted to 500, 80, 80, 50, 2, 6, and 1.2 PPM, respectively. A total of 1322 kg per ha of ammonium nitrate was applied during the growing season. The first two application rates were 17 kg per ha, the third was 56 kg per ha, the next six were 168 kg per ha and the final two were 112 kg per ha. These nitrogen topdressings were applied uniformly throughout the nursery beds, regardless of species. The first nitrogen applications began in mid-May and continued every 10 to 14 days until mid-September.

The target bed density for all the species was 54 to 57 seedlings per m^2. The beds were sown continuously with a single species until all seeds were sown. A gap of 2 to 4 m was created between seeds of differing tree species sown.

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The seedlings were irrigated intermittently during the entire growing season to supplement shortfalls in rain.

In early February 1994, all seedlings were undercut to provide a 25- to 30-cm long tap root. Prior to lifting, samples of seedlings from each species were obtained to identify ranges in seedling heights, stem caliper, and number of first-order-lateral roots (FOLR). From these data, visual criteria were developed to select the best 50 percent of the crop for each species for outplanting.

The planting site was a 2.5-ha area within a sweetgum fiber plantation study site. The entire study area was previously in pine and had been recently harvested and cleared of logging debris. Planting rows were laid out in a general north-south direction. Two hundred seedlings from each of the five species were randomly assigned planting locations at a 3.3 m x 3.3 m spacing. Because variations in soil profile characteristics were apparently far in excess of what one would assume based upon the soil maps available for that location (National Cooperative Soil Survey 1990), a second soil mapping of the planting site was subsequently completed to clarify observed soil differences.

The plantation was fertilized with diammonium phosphate (395 kg per ha) early in the second growing season. Early in the third (1996) growing season, ammonium nitrate was applied at 395 kg per ha. Competing vegetation including the annual weeds that were stimulated when the fertilizer was disked into the soil was controlled both with herbicides and mechanical means. Growth and survival data were obtained annually in early winter following leaf abscission.

The objective of this study was to determine the feasibility of developing a hardwood stand composed of five species. There was no interest in testing hypotheses related to growth and survival among the individual species. Hence, no formal statistical tests were performed.

RESULTS AND DISCUSSION

After 5 years, it appears that a sufficient number of competitive seedlings were available for each of the five species to warrant confidence that a desirable association of hardwood species has been established to satisfy any number of management options. Although the plantation is developing satisfactorily, soil conditions may lack the uniformity needed to adequately assess the effect of initial seedling grading. Significant variation in soil properties that impact root penetration precluded direct comparisons of loblolly pine (*Pinus taeda* L.) seedlings graded by FOLR characteristics (Kormanik and others 1998). However, within specific soil conditions, seedlings that had initially higher numbers of FOLR grew significantly better than those with fewer FOLR. A similar situation may be developing in this hardwood stand.

Edaphic Effects

The planting site was a small portion (less than 10 percent) of a larger sweetgum fiber plantation study site which was classified as a Rembert sandy loam in 1993. However, during outplanting it became obvious that the soil was not Rembert but rather a mosaic of several soil series. After the seedlings were outplanted, the soils in this study area were mapped and reclassified to a finer scale more suitable for this research study. Five clearly defined soil series were revealed in this soil complex (fig. 1). The soils were characterized by shallow residual plow layers, presence of plinthic horizons, (in some cases lying immediately under the shallow plow layer), and heavy mottling, which is indicative of poor drainage. Not all of these characteristics were uniformly present throughout the planting site. Variations in soil characteristics in this area are due to geological history and past agricultural practices. None of the mixed hardwood plantings overlapped into any of the soil classified as Rembert. The variation in soil characteristics had a significant impact on the development of individual seedlings at specific planting locations in spite of planting the best 50 percent of the seedlings from each species. Edaphic factors may impact forest plantations at specific locations far more than we realize.

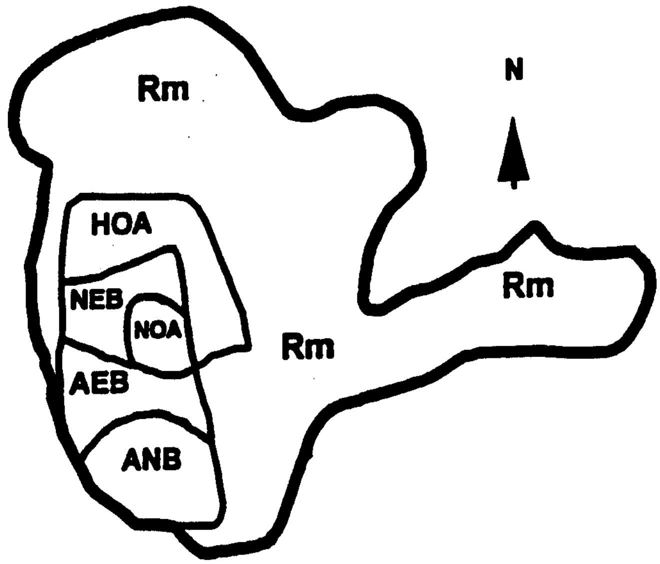

Figure 1—Five soil series identified on a 2.5-ha mixed hardwood planting area originally classified as a single soil series on a 25 ha area on the Crackerneck Wildlife Management area at the Savannah River Research Park, New Ellenton, South Carolina. Rembert sandy loam (Rm), Hornsville fine sandy loam (HoA), Neese loamy sand (NoR), Alley sand (AeB), Albany loamy sand (AnB).

Mortality

The initial 3 years were characterized by relatively normal rainfall patterns throughout the growing season and no mortality occurred among any of the five species. Severe droughts occurred during the fourth and fifth growing seasons, particularly between June 1 and mid-September. The drought was so severe that scheduled fertilizations were not applied early in the growing season because the soil was too hard to disk.

Survival data was obtained each year. Mortality was observed toward the end of the fourth growing season and occurred sporadically throughout the fifth growing season (table 1). Based upon the occurrence of excessively small, low vigor buds in certain trees of all species at the end of the fifth season, additional mortality of about 10 to 15 percent can be anticipated, especially if a severe drought occurs in the sixth growing season. Excluding those trees with low vigor buds, most other individuals of all species appear thrifty enough to withstand a moderate to severe drought during the sixth growing season. Soil horizons which restrict root penetration (i.e., plow pans, plinthic horizons, etc.)

Table 1—Heights, stem caliper, survival, and mean stem volume of five hardwood species in mixed species plantation in Crackerneck Wildlife Management Area at the Savannah River Research Park, Aiken SC

	1993		1996		1997		1998			
	Nursery		Third		Fourth		Fifth		Vol	
Species	Height	RCD	Height	D.b.h.	Height	D.b.h.	Height	D.b.h.	D^2H	Survival
	m	*cm*	*m*	*cm*	*m*	*cm*	*m*	*cm*	*cm^3*	*Percent*
Cherrybark oak	0.61	0.70	0.94	0.10	1.68	0.69	2.28	1.67	1341	84
Green ash	.93	1.43	1.95	1.16	3.07	2.00	3.71	3.08	4182	100
Swamp chestnut oak	.92	1.31	1.32	.36	2.02	1.17	2.59	2.44	2089	92
Sweetgum	1.18	1.21	1.85	1.22	3.08	2.90	3.77	4.53	9411	83
Water hickory	.61	1.20	1.08	.13	1.81	.79	2.19	1.35	649	95

seem to be associated with mortality, especially when these formations are close to the soil surface. Adequate survival is expected for all species and it is anticipated that this five-species association will thrive in the future.

Growth

Initial stem caliper and heights of the species at the nursery varied somewhat. Water hickory and CB were the shortest and CB had the smallest stem caliper (table 1). The relative rankings in height and diameters were comparable through the fifth growing season, and the wide variability among individual trees of all species can be attributed in part to edaphic conditions.

The impact of two consecutive drought seasons is depicted in fig. 2, where mean stem measurements are shown along with the largest and smallest individuals representative of each species. The ranking of species is relatively consistent regardless of whether mean height and diameter are compared or the largest or smallest individuals are compared. All species have individuals represented in the main crown canopy providing further evidence that a mixture of hardwood species can be maintained.

Sweetgum—Although sweetgum had the poorest survival rate (83 percent), it had by far the best average stem volume (table 1). At the end of the fifth growing season, it had more than twice the average stem volume of the other species (table 1). Visually, sweetgum appears to be the most vigorous of the five species and individual saplings have produced seed during both the fourth and fifth growing seasons. When found in adjacent positions in or between rows, the crowns of the sweetgum are frequently in contact and, to some degree, capable of shading competing understory plants. The larger dominant individual sweetgum is more uniformly present throughout the plantation. This may be indicative of broad site adaptability characteristic of this species. No deer (*Odocoileus virginianus*) browse has been observed on any sweetgum.

Green ash—No mortality was observed with GA. Overall, this tree species had the most uniform height and stem diameters of the five species even though it had been browsed heavily by deer during the initial two years (fig. 2). Green ash ranked second in average stem volume (table 1), but many trees became chlorotic and suffered premature

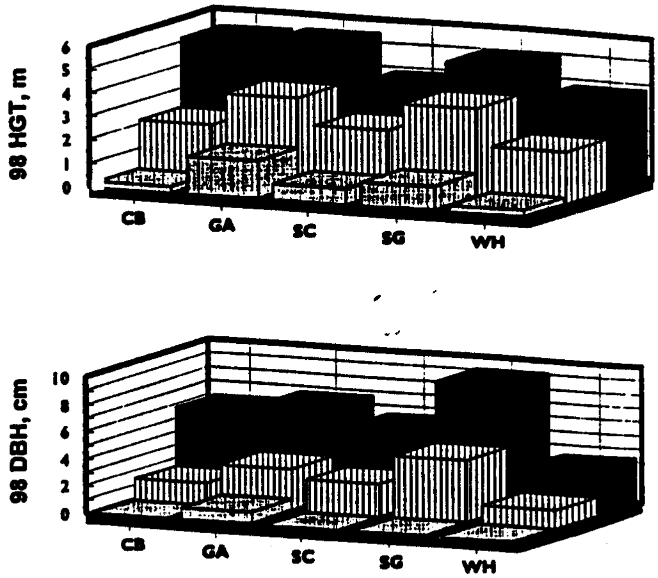

Figure 2—Mean stem heights and diameters (vertical striped) along with the largest (black) and smallest (grey) individuals for each species after 5 years in a mixed species planting. Cherrybark oak (CB), green ash (GA), swamp chestnut oak (SC), sweetgum (SG), and water hickory (WH).

defoliation as a result of the severe fifth-year drought. This chlorosis was evident on branch tips of the current year's growth. Interestingly, six individual GA also produced a limited seed crop in year 5. Adequate numbers of trees exhibited sufficient vigor such that their presence in the mixture appears promising.

Cherrybark oak—Although numerically ranking fourth in both height and stem caliper at the end of the fifth growing season, CB had many of the tallest, as well as the smallest, individuals in the study (fig. 2). The best 10 percent of the CB rivaled the best SG and GA in size and vigor, and their continued presence in a future stand appears to be assured. No significant deer browse has been observed on this species.

Swamp chestnut oak—Swamp chestnut oak is among the most highly prized mast species on southern bottomlands. Even though survival has been outstanding, the soil conditions on this study site are not well suited for optimal development of this species (fig. 2). Swamp chestnut oak ranked third in survival as well as in average stem volume (table 1). Sufficient competitive individual SC are scattered throughout the planting to ensure a viable future presence in the stand. No significant deer browse has been observed on this species.

Water hickory—Water hickory was an unknown variable when this study was initiated. It is well known that nursery production of other hickory species has been unsatisfactory, and no information regarding techniques for growing WH could be found (Williams and Hanks 1994). Fortunately, this species developed better in the nursery than did other hickories and suitable planting stock was obtained. Although average heights after 5 years were comparable to CB, and perhaps SC, fewer WH dominated the canopy at specific planting locations (fig. 2). This was the only species defoliated by the tent caterpillar (*Malacosoma disstria*) in both the fourth and fifth year. The defoliation was very severe during the fifth growing season with well over one-half of the WH affected by mid-September. Currently, a number of competitive WH are present in this study. It is anticipated that this species will be represented as the stand matures. Little has been reported on artificial regeneration of this species (Francis 1990), but the effects of slow early growth and shade intolerance may be overcome by early provision of free growing space.

CONCLUSION

A complex mosaic of soils with plow layers, plinthic horizons, and other impediments to root growth have significantly affected this hardwood plantation. That being stated, the acceptable growth by the majority of individuals from all species suggests that grading and outplanting only the best 50 percent of a specific nursery crop may be quite effective. Although drought for 2 consecutive years resulted in some mortality, it has not materially affected the future development of this five-species association. This hardwood mixture appears to be thriving because adequate growing space and sunlight have been assured. The benefit of controlling competition has, to some degree, been reduced by the extreme variability in soil drainage and impediment layers affecting root development.

REFERENCES

Francis, J.K. 1990. *Carya aquatica* (Michx. f.) Nutt. In: Burns, R.M.; Hankala, B.H., coord. Silvics of North America, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 186-189. Vol. 2.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994a. Irrigating and fertilizing to grow better nursery seedlings. In: Proceedings of northeastern and intermountain forest and conservation nursery associations; 1993 August 2-5; St. Louis, MO. Gen. Tech. Rep. RM-243. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 115-121.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994b. Toward a single nursery protocol for growing oak seedlings. In: Proceedings of the 22nd southern forest tree improvement conference; 1993 June 14-17; Atlanta. [Place of publication unknown]: [Publisher unknown]: 89-98.

Kormanik, P.P.; Sung, S.S.; Zarnoch, S.J. 1998. Immature loblolly pine growth and biomass accumulation: correlations with seedlings initial first-order later roots. Southern Journal of Applied Forestry. 22: 117-123.

National Cooperative Soil Survey. 1990. Soil survey of Savannah River plant areas, parts of Aiken, Barnwell, and Allendale Counties, South Carolina. [Place of publication unknown]: National Cooperative Soil Survey and U.S. Department of Agriculture, Soil Conservation Service. 127 p.

Williams, R.D.; Hanks, S.H. 1994. Hardwood nursery guide. Agric. Handb. 473. Washington, DC: U.S. Department of Agriculture, Forest Service. 78 p.